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THE EFFECT OF WATER AND SODIUM CHLORIDE INTAKE ON SODIUM CHLORIDE CONTENT IN HUMAN PERSPIRATION AND BLOOD AT HIGH AMBIENT TEMPERATURES

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THE EFFECT OF WATER AND SODIUM CHLORIDE INTAKE ON SODIUM CHLORIDE CONTENT IN HUMAN PERSPIRATION AND BLOOD AT HIGH AMBIENT TEMPERATURES[1] /297

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This study is part of a series examining the effects of various ambient temperatures and relative humidities on the organism. They were conducted in the State Institute for Industrial Safety in Moscow.

The purpose here was to determine what influence high ambient temperatures exert on the water-sodium chloride balance of the body and especially what changes in water-sodium chloride metabolism are caused by perspiring. Perspiration secretion is a method by which the body emits increased heat. The secretion of perspiration is influenced by the central nervous system. It is a nervously stimulated glandular function, which is to a great extent dependent on blood circulation (Levy, Kittsteiner). Recovery of pure perspiration, free of skin sebum and castoff epithelium, is very difficult. The technical difficulties inherent in the extraction of perspiration became sources of error in qualitative experiments. During profuse perspiration secretion, which is stimulated by pilocarpine or steam baths, these difficulties decrease. In quantitative experiments, the fact that evaporation losses occur must be borne in mind. Sodium chloride predominates by far among the organic components of perspiration. During perspiration stimulation procedures in a light bath, hot air bath and steam bath, E. Crame determined that the residue of human perspiration shows a relatively constant NaCl content of 0.64-0.74 percent. Most authors (Rubner, Spitta, Erismann, /298 Cramer) have been interested either in the quantitative and qualitative composition of perspiration or in the water secretion of the skin under various external conditions. The results of these authors as to the relationship between secretion and NaCl content (which we studied in a first curve) do not agree. Whereas Spitta and E. Cramer obtained relatively constant NaCl values, Kittsteiner determined that NaCl content is so dependent on secretion that it increases as the amount of secretion per unit of time increases. These contradictory findings may be partially due to the type of secretion stimulation and the manner of collection

[1]This work was undertaken under the direction of Director Dr. Lewitzky and completed under the direction of Professor S. Kaplun.

used. Furthermore, Cohnheim, Kreglinger, Tobler and Weber, in their study "zur Physiologie des Wassers und NaCl" (The Physiology of Water and NaCl) determined that Cl elimination through perspiration is so great that it may cause Cl-hunger. This Cl deficiency from heavy perspiration leads to Cl retention in succeeding days, which means that weight loss after heavy perspiring will not be recovered during that period. Based on clinical observations concerning the relationship between water and salt in the organism, Tobler concluded that one must differentiate between three stages in weight loss due to water secretion:

1. Concentration loss, which occurs when weight loss due to water secretion is slight and may be recovered by the intake of water.

2. Reduction loss, when weight loss may only be compensated for by water and salt intake.

3. Destruction loss, which is accompanied by tissue damage. In these cases, NaCl administration leads to edema.

According to Tobler's terminology, we must consider weight loss through perspiration as reduction loss. This explanation agrees with the observations of Winkhaus, who examined miners working at high atmospheric temperatures. According to his data, 4-5 liters of water cannot compensate for weight loss suffered on one day due to heavy perspiration secretion. The administration of water only leads to "water poisoning," whereas increased NaCl prevents this. The effects of water and NaCl on diuresis have always received great attention within the field of water-NaCl metabolism. Among others, F. Brunn (Ref. 2) published studies on this subject. In Brunn's experiments, the subject, under bed rest, drank /299
1 liter of water in the morning. Diuresis, which passed quickly, developed in 3 hours. It was lessened by the addition of NaCl (see Table I).

Table I (according to Brunn)

Liquid intake	4-hr urine volume	Specific gravity	NaCl in the urine
1 l 0.9 % NaCl	500 cc		
1 l 2.4 % NaCl	330 cc	1010-1013	4.5 g
1 l distilled water	1000 cc	1001	4.5 g

Kittsteiner's experiments show that the secreted amounts of urine and perspiration have a nearly reciprocal relationship, a finding also confirmed by other authors.

The role played by the NaCl in the blood and other body liquids in the water-salt metabolism is extremely important. Research in the last few years (Zondek, Kraus) into the part played by the electrolytes in life processes shows that there is a close relationship between the electrolyte balance of the blood and the functional condition of the body. In this connection, we undertook to determine the dynamics of chloride in perspiration, the NaCl concentration in the blood and perspiration, and the total NaCl loss to the body. Further, we conducted comparative studies on the effect of water and saline solution intake on the percentage of chlorides in the blood and perspiration at high ambient temperatures. This experimental design allowed us to explain a phenomenon observed in daily industrial health practice which to date has not been explained satisfactorily. This is the fact that workers in hot industrial installations (both in the USSR and abroad) drink salt water prepared by dissolving a few handfuls of salt in their drinking water.

The previously used methods of perspiration collection (including rubber bags, sponges, specially prepared underclothes, glass cylinders) were too often accompanied by water loss through evaporation or due to abnormal conditions. We realized at the beginning of our study that we must choose a method which would suit our purpose by approaching natural conditions as closely as possible and by eliminating evaporation. We used the very comfortable Bang micromethod. The following method of /300
perspiration collection was used: The pertinent part of the body was carefully washed with distilled water and dried with cotton before the perspiration procedure started. Cleaning with alcohol or other chemicals was avoided purposely, to preclude local skin irritations. As the perspiration drops emerged they were absorbed by a piece of filter paper, which was immediately reweighed. Collection and subsequent weighing (by torsion scale) of the perspiration-soaked paper was completed within 15 seconds. This method of collection has the advantage over previous methods of avoiding evaporation without disrupting normal perspiration secretion, besides permitting collection of fresh perspiration at any time during the experiment. To avoid evaporation from the surface of the filter paper when it was carried from the test chamber to the scale, we constructed a simple apparatus. It consists of a glass cylinder stoppered on one end with a damp piece of cotton and with a cork on the other. The cork stopper has a narrow slit through which bone-tipped forceps may be inserted.

The chlorine determination in the blood, in blood serum and in perspiration was conducted according to the Bang micromethod. The blood serum was extracted by coagulation in a Pasteur pipette, which was stoppered immediately after the blood was taken with a cork coated with paraffin. After some time, the serum which was still liquid was removed with another pipette, soaked into filter paper, and subjected to the usual procedures. We made a blood serum chlorine determination because there is a difference in the chlorine content of erythrocytes and plasma. According to Abderhalden, Rusznyak and Rona, the erythrocytes contain 40-60 percent of the chlorine in plasma. Since blood thickening occurs during perspiration, a decrease in the percentile NaCl content could be caused by a relative increase in erythrocytes. For this reason, a determination of the percentile NaCl content of the blood is not sufficient for evaluation of the intermediate salt metabolism during perspiration.

A control sample was always taken during chlorine determinations in blood and perspiration. Comparison of the values obtained showed excellent correlation (to 0.002-0.03 percent) (Table II).

Table II /301

Subject	Date	40' NaCl %	80' NaCl %	120' NaCl %	150' NaCl %	180' NaCl %
K.	21 September	0.4557	0.6094	0.6400	-	-
	21 September	0.4859	0.6132	0.6549	-	-
	29 September	0.3645	0.5850	0.6052	-	-
	29 September	0.3680	0.5800	0.6036	-	-
B-w	12 April	0.1563	0.2134	0.2250	0.2414	0.2357
B-w	12 April	0.1567	0.2231	0.2454	0.2421	0.2416
B-w	14 April	0.1680	0.1672	0.1791	0.2021	0.2123
	14 April	0.1763	0.1672	0.1780	-	0.2177
K-w	22 February	0.6623	0.8085	0.8929	-	-
	22 February	0.6746	0.7953	0.9078	-	-
	22 March	0.7553	0.8531	0.9506	1.000	1.231
	22 March	0.7313	0.8520	0.9520	1.000	-

The tests were conducted in an experimental heat chamber[1] and were carried out at 46°C and 50 percent relative humidity. These conditions

[1]The experimental heat chamber was constructed in 1925 according to the specifications of Dr. Lewitzky. The walls consist of glass plates 0.5 cm thick. All variations in temperature, relative humidity, air movement, lighting conditions and dust particles in the air may be reproduced in this chamber. The cubature of the chamber is 41.8 cm. The ventilation arrangement permits stable air circulation. The air can be changed completely in 10 minutes by use of the pressure intake and suction valves and is warmed by 4 radiators. The air is humidified by water vapor piped in from a steam boiler. Temperature variations are never greater than

were kept as constant as possible during each test series. Students aged 22-25 were the subjects. They came to the tests in the morning and with empty stomachs. The experiments were performed with the subjects nude and resting prone. Blood was taken from the fingertips and perspiration was collected from the forehead. To eliminate the influence of the high chamber temperatures on the physical characteristics of the blood, the subjects extended their arms through a window in the chamber when blood was drawn. The living habits and diet of the subjects were regular. Six subjects were used in the experiments.

Our experiments were arranged in three series. During the first series, the subject received no water. He received 2 liters of water in /304
the second series and 2 liters of 1 percent saline solution during the third series. Experiments in the first series lasted 2 hours, while those in the second and third series lasted 3 hours. Blood extraction, weighing, and perspiration collection were conducted at predetermined time intervals, namely at 0, 40, 80, 120, 150 and 180 minutes after the start of the experiment. The same procedure was followed in measurement of body temperature (per os) and pulse. The first perspiration sample was taken 40 minutes after the start of the experiment, since our experience showed that perspiration begins after 30-40 minutes at 46°C and 50 percent relative humidity.

The following may be determined from the tables: Weight loss in the experiments conducted without water intake reached about 1000 g[1] in 2 hours. This value is a constant for the given subject, and also was the mean for all subjects (only in B-n (Table III) did the weight loss climb to 1800 g).

Secretion velocity is subject to the same variations: we never obtained constant values in the same time period. For example, in the first interval weight loss (perspiration volume) was 200 g, while it was 400 g in both the second and third intervals, in one day. Another time the weight loss of the same subject was 200 g in the first interval, 500 g in the second and 300 g in the third (Table V).

The total amount of NaCl secreted in perspiration within 2 hours reached 7 g. The NaCl content of the perspiration is dependent on the

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(footnote continued from previous page) 1°C and relative humidity variation never more than 5 percent. Lighting in all colors of the spectrum may be produced. Artificial rain can be generated by a very fine water spray.

[1]Part of this weight loss is caused by water loss through respiration and CO_2 elimination during perspiration. This loss is so slight, however, (at 46°C and 50 percent relative humidity) that it may be disregarded.

Table III
Subject B-n

Series	Date	Test substance	0′	40′	80′	120′	150′	180′	40′	80′	120′	150′	180′	Total weight loss (g)	Amount of NaCl secreted or retained	Liquid intake Water	NaCl (1%)
		Perspiration	–	0.40	0.56	0.61	–	–									
	2 April	Blood	0.54	0.58	0.53	0.52	–	–	400	900	500	–	–	1800	– 9.24	–	–
I		Serum	0.63	–	–	0.60	–	–									
	7 April	Perspiration	–	0.35	0.54	0.63	–	–									
		Blood	0.55	0.54	0.52	0.52	–	–	300	700	600	–	–	1600	– 8.61	–	–
		Serum	0.65	–	–	0.62	–	–									
		Perspiration	–	0.52	0.61	0.61	0.63	0.64									
	29 April	Blood	0.55	0.56	0.56	–	0.53	0.51	400	600	800	400	500	2700	–16.09	2000	–
II		Serum	0.66	–	–	–	–	0.63									
	9 April	Perspiration	–	0.29	0.47	0.50	0.58	0.56									
		Blood	0.54	0.52	0.51	0.53	0.51	0.51	400	500	800	600	300	2600	–12.67	2000	–
		Serum	0.65	–	–	–	–	0.63									
		Perspiration	–	0.25	0.51	0.53	0.58	0.58									
	12 April	Blood	0.54	0.58	0.59	0.57	0.58	0.60	300	500	600	400	300	2100	– 9.46	–	2000
III		Serum	0.65	–	–	–	–	0.72									
	14 April	Perspiration	–	0.33	0.57	0.58	0.56	0.61									
		Blood	0.56	0.56	0.58	0.58	0.58	0.58	700	500	400	500	300	2400	– 7.87	–	2000
		Serum	0.66	–	–	–	–	0.70									

Table IV
Subject R-w

Series	Date	Test substance	0′	40′	80′	120′	150′	180′	40′	80′	120′	150′	180′	Total weight loss (g)	Amount of NaCl secreted or retained	Liquid intake: Water	Liquid intake: NaCl (1%)
	29 Jan.	Perspiration	–	0.73	0.75	0.78	–	–									
		Blood	0.56	–	–	0.50	–	–	200	400	400	–	–	1000	– 7.58	–	–
I		Serum	0.71	–	–	0.67	–	–									
	1 Feb.	Perspiration	–	0.70	0.80	0.94	–	–									
		Blood	0.55	–	–	0.53	–	–	200	560	300	–	–	1000	– 8.22	–	–
		Serum	0.75	–	–	0.70	–	–									
		Perspiration	–	0.67	0.74	0.78	0.86	0.94									
		Blood	0.54	–	–	–	–	0.46	175	450	925	450	525	2525	–20.26	2000	–
II	12 Feb.	Serum	0.67	–	–	–	–	0.64									
	17 Feb.	Perspiration	–	0.67	0.76	0.86	0.86	0.88									
		Blood	0.56	0.56	0.55	0.53	0.51	0.50	200	200	600	200	105	2250	–19.01	2000	–
		Serum	0.70	–	–	–	–	0.63									
	24 Feb.	Perspiration	–	0.55	0.70	0.88	0.90	0.87									
		Blood	0.56	0.55	0.57	0.54	0.56	0.58	100	650	450	350	300	1850	+ 5.20	–	2000
III		Serum	0.64	–	–	–	–	0.67									
	3 March	Perspiration	–	0.65	0.82	0.80	0.83	0.79									
		Blood	0.57	0.58	0.58	0.57	0.57	0.60	200	600	350	500	200	1850	+ 5.25	–	2000
		Serum	0.64	–	–	–	–	0.67									

Table V

Subject	Date	Weight loss (g)					NaCl in perspiration (g)					Liquid intake (cc)	
		40'	80'	120'	150'	180'	40'	80'	120'	150'	180'	Water	1% NaCl
R-W	29 January	200	400	400	-	-	1.40	3.00	3.12	-	-	-	-
	1 February	200	500	300	-	-	1.40	4.00	2.82	-	-	-	-
	12 February	175	450	925	450	570	1.17	3.33	7.21	3.87	4.7	2000	-
	17 February	200	200	600	200	1050	1.34	1.52	3.44	2.15	10.56	2000	-
	24 February	100	650	450	350	300	0.53	4.55	3.96	3.15	2.61	-	2000
	3 March	200	600	350	500	200	1.3	4.92	2.8	4.15	1.58	-	2000

length of the experiment, increasing as the experiment is extended. We see in Table III that in the 120th minute it increases to 0.94 percent, whereas it was only 0.70 percent at the 40th minute[1]. We observed the following in the first series of experiments: a body weight decrease of 1000 g, a decrease in percentile NaCl content in the blood and its increase in perspiration, and a significant loss in total NaCl, which reached 7 g. /305

In the second series of experiments, the subject received 2 l of water in amounts of 500 cc at the beginning of each interval and manifested more severe perspiration secretion; the weight loss reached 2250 g. Although the experimental conditions were held constant in this series, we obtained varying amounts of perspiration. We could further confirm that the percentile content of NaCl in the perspiration increased as the experiment progressed (from 0.67 to 0.86 percent). This shows that the NaCl content is only dependent on the length of the experiment. A significant decrease in the NaCl content of the blood also occurs with water intake. Total NaCl loss (Ref. 2) through the skin reached 19 g. Diuresis occurred with water intake, independently of perspiration secretion. Urine secretion reached 1000 cc.

These data lead to the conclusion that water intake has no influence on shifts in the NaCl level of the blood. Water intake during perspiration leads to even larger NaCl secretion and water elimination (through the kidneys and the skin).

In the experiments conducted in the third series, the subject received 500 cc of 1 percent solution (5g NaCl) at the beginning of each interval, or a total of four doses. An increase in the percentile NaCl content of the blood and blood serum followed. These increases were subject to variations, but the levels always remained higher than normal.

Body temperature increased in each case in the test subject B-n in Table III. It increased about 1°C in 120-180 minutes, or from 36.8°C to 37.7°C. The highest temperature registered was 38.2°C.

The body weight loss was smaller than the amount of water administered. It reached 1860 g. The total loss[2] of NaCl was about 14 g.

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[1]In this case, therefore, the increased glandular activity is accompanied by an increase in NaCl concentration. The percentile NaCl content of the blood decreases (from 55-1/2 to 53-1/2).

[2]The amount of NaCl secreted was calculated by multiplying the weight loss by the percentile NaCl content in the perspiration taken from the forehead. The possiblity of such a calculation was confirmed in a series of preparatory experiments conducted in order to determine the NaCl

The phenomenon of retarded elimination is related to retention processes in the organism when the NaCl balance is correspondingly positive[1]. Since the experimental conditions were identical during the entire series, these changes may be attributed to the effect of NaCl. /306

No dependence exists between the NaCl content of the perspiration and the amount of NaCl administered. The same may be said for water intake. With regard to pulse and body temperature, the readings taken in the third series showed that the increase was somewhat retarded. All test subjects were aware of the fact that saline solution intake made it easier to undergo the experimental conditions. They did not complain of headaches and were able to read during the experiment, which they had not been able to allow in the first and second series. Furthermore, they all expressed their willingness to remain for a longer period in the chamber.

Summary

1. The percentile NaCl content in perspiration is dependent on the length of the experiment, increasing as the time of test is extended.

2. Perspiration causes a decrease in the NaCl content of whole blood and blood serum and changes in the intermediate NaCl metabolism.

3. Water intake during perspiration leads to greater secretion of NaCl and water.

4. The changes wrought by perspiration on water-NaCl metabolism may be inhibited by administration of a 1 percent saline solution. /307

(footnote continued from previous page) content in perspiration collected from various parts of the body. According to both Kittsteiner's and our own data, the percentile NaCl content in facial perspiration is higher than that taken from other parts of the body. As a result, our values, which were calculated from facial perspiration, are not absolute, but represent "conditional values."

These values have more than their practical significance in the determination of the amount of NaCl intake necessary to compensate for loss. They also have theoretical interest in the comparison of the amounts of NaCl secreted when different liquids are drunk (i.e., the system of salt addition made to their fluids by workers on the job. Samples are now being evaluated in our laboratories).

[1] The amount of NaCl retained was calculated by subtracting the amount secreted from the amount ingested (for example: 20 g - 9.46 g = 10.54 g).

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